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Current transformer failure caused by electric field associated to circuit breaker and pollution in 500 kV substations

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ABSTRACT

In the last years, the power demand of Perú keeps rising and the power system expands the scale extraordinary, in order to transport more energy, the overhead lines and substations in 500 kV has been built, especially in the last decade. Currently, the international standards for the minimum safety distances in electrical substations have been designed considering the insulation co-ordination, however if some designer considers the equipment installed in the same phase, there are just a recommendation in some papers, without considers the effect of electric and magnetic field and contamination between assets.

This research has analyzed a failure mode caused by electric field in 500 kV substations, the problem was focus on current transformers. Three current transformers have failed, exploiting near the circuit breakers in the same phase, the analysis and the root cause of this fault has been developed in a special condition, the coast of Peru, and the novel contribution is a recommendation for the physical layout in substations, insulation coordination and standards of electric field for the design of substations for 500kV.

1. Introduction

In the last years, the consumption of electricity is continuously growing, in the power system to consumers is carried out using high voltage power lines and substations, in Perú the transmission systems has been built across the country in a voltage of 500 kV [1], in order to further utilize the power lines for industrial and mining needed, however some particulars problems has been detected, as pollution caused by sea winds [2], among others. This type of voltage level in the coast doesn't have lightning problems [3], but the electric and magnetic problems should be considered for invisible degradation, even more, the international standards don't consider some characteristics in the design, it is a real failure mode for the maintenance [4].

The modern substations for high voltage have required special considerations for the electrical phenomenon in this voltage level, the recovery transitory voltage in the circuit breaker [1, 23], the overvoltage for the series capacitors in the large overhead lines, power transformers with degradation [27, 28], rupture of the cables and guard wires [30] and FACT failures with stability power system problems [31].

In 500 kV substations, physical layout drawings have written with the insulation co-ordination standard [5], besides due to the fact that the power frequency is 60 Hz, time harmonic electric and magnetic fields are considered quasistatic [6], therefore, electric field is calculated separately.

Different approaches for electric field on Overhead lines (OHL) and substations has been demonstrated with simple geometries in a 2D models, without a correct approach [7]. Due to this problem, the 3D modeling with complex geometries has been considered

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with Charge simulation methods (CSM) for electric field in substations, other as hybrid CSM has been worked too [8, 9]. In 2018, a computation of electric fields inside substation has been performed based on integral equations approach, it shape functions of change densities over the elements of HV facility [10]. However the electric and magnetic field haven't calculated for an interaction in the same phase and with pollutions components. Finally, others internationals standards just recommend a human exposure to electromagnetic field for 0 to 3 kHz, for an electromagnetic and human interaction in the substations and OHL [11]. Generally accepted guidelines have been established for safe public and occupational exposure to power-frequency electromagnetic field.

The reference levels for general public exposure to 60 Hz, electric and magnetic field are, according to International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, are the followings [14]:

- Electric field strength, E < 5 kV/m
- Magnetic field strength, H < 80 A/m
- Magnetic flux density, B < 100 μT

And for occupations exposure are the followings:

- Electric field strength, E < 10 kV/m
- Magnetic field strength, H < 400 A/m
- Magnetic flux density, B < 500 μT

The problem solved in this research, is related to the development of a failure assessment using finite elements for high voltage current transformers and circuit breaker, two important assets to ensure the normal operation of power system, of which the reliability is largely dependent on the normal operation of the correct operation systems [12], to find various approach. The system can be applicable in the fault warning, maintenance of current transformer, to provide bases for design and physical layout plan in new 500 kV substations [21]. The purpose of this research is to explain how an electric field (EF) with pollution and humidity conditions affect the current transformer caused by high influence of EF, finally, it has been analyzed by a root caused analysis (RCA) in 3 current transformers explosion, it has occurred in Peru, in the same substation for the same one and half scheme at 500 kV substation.

Section 2 considers the internal assessment for 500 kV substations layout, calculations methods; in Section 3, failure analysis has been done with an implementation of adaptive approximation, it describes the input data, electric potentials, gradient potentials in the equipment and oil. Section 4 has considered the root cause analysis for this equipment explosion, in the next Section 5, the numerical benchmarking is done, and finally, the last section is the conclusion for the knowledge management in energy companies, for the internationals standards upgraded and future substations design.

2. Internal assessment

2.1. 500 kV substations layout

Substations are points in the power network where transmission lines and distribution feeders are connected though circuit breakers or switches via bus bars and transformer. This allows for the control of power flows in the network and general switching operations for maintenance purposes. In an ideal situation all circuits and substation equipment would be duplicated such that following a fault or during maintenance a connection remains available. This would involve high cost, method have therefore been adopted to achieve a compromise between complete security of supply and capital investment. In 500 kV, the layout category is the number 1: No outage necessary within the substation for either maintenance or fault. The 500 kV layout is 1½ Breaker scheme, in Fig. 1, under maintenance conditions in the circuit breaker area [13].

In Fig. 1, it offers the circuit breaker bypass facilities and security of the mesh arrangement coupled with some of the flexibility, availability, reliability and maintainability of the double bus bar scheme [24]. The layout is used at important high-voltage substation and large generating substation in the USA, Asia, and Latin America where the cost can be offset against high reliability requirements. Essentially the scheme in Fig. 1 requires 1½ circuit breaker per connected transmission line or transformer circuit and hence the name of this configuration.

The safety distance means the minimum distance to be maintained in air between the live part of the equipment or conductor on the one hand and the earth or another piece of equipment or conductor on which it is necessary to carry out work on the other. A basic value relates to the voltage impulse withstand for the substation, for the design, it is used the IEC international standards [5], however it has recommendations for the equipment installed in the same phase, for maintenance and overhaul purpose, the typical distances between substation equipment are indicated in Table 1.

In Table 1, a task point is this distance is between the geometric centers of each equipment.

2.2. Calculation methods

The three-dimension (3-D) finite element method (FEM) was employed to calculate the electric field distribution of current transformer and circuit breaker in the 500 kV substation, in Figs 2 and 3. In order to have a better simulation of the actual situation, in this research, the actual shape among the equipment (circuit breaker – current transformer), the ground, the interaction between different phase have been taken into consideration, likewise the safety distances in the design. The basic assumptions and simplifying